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Experimental analysis on backfilling rehabilitation with Coal Combustion By-Products (CCBs) for abandoned Small Scale Coal Mines

Bachelor Thesis

by

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Abstract

This thesis focused on experimental analysis of the rehabilitated area in the abandoned small-scale coal mine in the Nalaikh mining area. The soil analysis is conducted at several spots in the rehabilitated shafts since the impacts of the rehabilitation by backfilling method could be more detectable in soil than in the water and air environment. Additionally, backfilling method of coal fly ash and mining reclamation were researched and mentioned, including a review of Mongolian examples of the backfilling method and the BASMIC project.

The rehabilitated area of Nalaikh mining has a neutral pH environment and loamy sand soil texture that is not suitable for growing plants. The mean value of the pH environment is 7.5 in the rehabilitated area. The concentration of heavy metals was determined to evaluate the pollution level. In most cases, the content of elements did not exceed maximum permissible values. It was contaminated by copper, zinc, and arsenic. Zinc concentration (610 mg/kg) of spot A01 is 4 times higher than the topsoil of reference soil sample and almost 2 times higher than Mongolian standard. The area which contains the maximum (430 mg/kg) value of Cu is A06, around the landfill area of the Nalaikh district. Comparing to the reference soil, arsenic pollution is 2 times high at spot A01 due to the fly ash of the power plant. As for the lead pollution, maximum concentration is 120 mg/kg at spot A05. Compared to the reference topsoil, it is 12 times higher. Spot A05 is located just next to the mine hole, collapsed construction and the road. Those are the main reasons of pollution including residue of coal mine, construction materials, car emissions so on.

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1. Introduction

Artisanal and Small-scale mining is a form of economic activity that has been important to many in Mongolia since the 1990s. It has been a large informal economic sector mostly driven by poverty. Artisanal mining has destructive impacts on the environment since the miners are mostly unskilled, lack knowledge, and have little respect for the environment.

Coal is the main energy source in Mongolia while a slight portion is produced from renewable energy sources such as solar, wind, and hydro and will most likely continue to be so. Coal combustion by-products (CCBs) are generated during the process of burning coal by power plants and by coal combustion in the ger district. Mongolian power plants generate more than 800.000 t/a of CCBs (1). Most of the CCBs are usually thrown away without any environmental and economic benefits. Therefore, reusing CCBs is one of the best solutions for backfilling in small-scale coal mining. Mine backfill is a well-established and proven practice within the underground mining industry.

Backfilling, which is one of the parts of the rehabilitation, is environmentally and economically friendly for abandoned small-scale coal mines by using coal combustion by-products. The backfill material provides support to the surrounding rock mass, reduces wasteful dilution, enables a safe working area for production activities, and mitigates the risk of surface subsidence. By combining tailing materials in the backfill, it is possible to reduce the environmental footprint of the mine and assist with final site rehabilitation. Therefore, cemented paste backfill (CPB) has become an important component of underground mining operations. CPB is a mixture of tailings, water, and cement used to fill underground holes.

There are four types of CCBs, which are bottom slag, bottom ash, fly ash, and cyclone ash in Mongolia. Based on the previous research work which is the BASMIC project, fly ash of Thermal Power Plant #4 is the most appropriate backfilling material for underground mining holes. The BASMIC project's main objective was to investigate whether there are opportunities to use at the German-Mongolian Institute for Resources and Technology (GMIT), Ulaanbaatar, Mongolia, CCBs from the power plants for backfilling and securing abandoned small mining sites in Nalaikh, which is one of the nine districts of Ulaanbaatar city (1).

MDU LLC has implemented a project named "Rehabilitation of 1-hectare mining area" in 2020 and its location is in Ulaanbaatar city, Nalaikh district. The project was initiated and supported by the Environmental Department of Municipality according to the yearly plan to rehabilitate the abandoned small-scale coal minings in the Nalaikh area. During the project, fly ash from the Amgalan Power Plant was used as a backfilling material for the rehabilitation of

the coal mining area. To the current knowledge, this kind of backfilling technology is the first-ever known method in the Nalaikh area, probably in Mongolia. Therefore, there is no assessment to evaluate the impacts of the CCBs on the environment. It should be mentioned that the relevant analysis has not been conducted before the rehabilitation process done by MDU LLC in the study area.

The current work aims to cover the following:

- Impacts of coal mines on the environment
- Overview of rehabilitation methods in small-scale mines
- Review mine backfilling method
- Review the BASMIC project
- Conduct soil analysis of the abandoned small-scale coal mine in the Nalaikh area
- Analysis of the backfilling method for abandoned small-scale coal mine
- Compare the results with background spots nearby the rehabilitated area
- Assess the impacts on the soil environment after backfilling
- Discuss the results and give suggestions for further work.

Due to a lack of previous research before the backfilling process in the study area, the current work is limited to including soil analysis such as the pH value, heavy metals, and mechanical composition.

2. State of art

2.1 Environmental impacts of small-scale mines

There are many small-scale coal and gold mines in Mongolia. The main challenge is to manage small-scale mining in an environmentally-friendly and economically-efficient way. Also, most of them are running illegally because there is a lack of legal framework in small-scale mining fields.

Environmental impacts of mining activities include air pollution, water quality issues, biodiversity effects as well as climate change effects. Mining area that is mostly not rehabilitated for agricultural use, although some is, rivers polluted with acid mine drainage, areas of soil subsidence and underground fires, air pollution from dust, and the associated effects of coal-fired power stations with inadequate pollution control. The main two problems are water and air pollution. The largest water quality problem associated with coal mining is undoubtedly acid mine drainage. Acid mine drainage consists of the following three interrelated issues:

1st: The pyrite in the rock gives rise to water with a low pH.

2nd: This acid water in turn mobilizes heavy metals from the environment, in the mine, or the river course from the sediments.

3th: Treating the water with calcium to raise the pH, makes the water more saline, a problem that requires expensive and energy-intensive reverse osmosis or similar processes (2). It is very difficult, if not impossible, to avoid acid mine drainage. Rock once broken up is open to oxygen, which reacts with the pyrite in both the coal and the surrounding rocks. Once water flows over this, acid mine drainage follows.

An example of water pollution due to gold mining is a well-known case of gold mining in Khongor soum. A river named the Khuiten is located in Khongor soum, Darkhan-Uul aimag. Along the river, many herder families reside in three seasons except for winter and also some agricultural areas benefit from the river. Unfortunately, artisanal gold mining activities are running at the beginning of the river using mercury and sodium cyanide to extract the remaining gold in the mining waste. Its acid mine drainage polluted the drinking water during the three seasons and the soil was contaminated by mercury. The case aroused considerable attention from the public and is considered the first major chemical emergency due to the artisanal gold mining in Mongolia.

Air pollution from mining activities leads to health risks. Generally, methane (CH₄) emissions from mines and particulate matter (PM) emissions are the two main sources of air pollution that are created during the coal mining process. CH₄ emissions are one of the main factors contributing to global warming. In addition, particulate matter can cause significant respiratory damage as well as premature death. For example, the Nalaikh coal mine was established in 1922 at first and produced over 600,000-ton coal within a year in that period. One of the reasons that this coal mining stopped in the 1990s was the explosion of methane gas. But many small companies and local people have started to mine the coal illegally after the explosion. During the coal production process, some accidents happened including landslides and explosions. It shows that most of them did not consider their health and the environment. In the current situation, this mining site became an abandoned small-scale coal mining area without any rehabilitation activities. But just next to the mining area, around 40 thousand people live and according to the long- and mid-term development plan of Mongolia, the Nalaikh district is planned to be developed for construction materials production, trade, transport logistics, technology park, and processing industry. Therefore, rehabilitation of mining is one of the pressing issues.



Figure 1. Nalaikh's abandoned small-scale coal mine area

2.2 Rehabilitation in mining

2.2.1 Mining reclamation

Small-scale mines which have been abandoned for numerous a long time are one of the pressing issues in Mongolia. Mine closure refers to the complete process of shutting down a mine's operations, including planning, decommissioning, reclamation, and continuing

monitoring. While the mining process goes on, chemicals and heavy metals are used. So, these chemicals and heavy metals are released and discharged into the environment. They influence the water and air, harming the entirety of the land, and influencing the local agriculture and human and animal health. Due to the impacts that mining has on the environment, the land which has been mined must be restored, in a few ways, so that it can stay healthy, without harming or influencing the nearby surrounding in a negative manner.

Mined lands are recovered for various good post-mining uses in collaboration with the local community through reclamation, which is one of the most important aspects of the mine closure process. As for the open-pit mines, progressive, segmental, intermediate, or postmining reclamation are the four reclamation strategies that can be used (3). Progressive reclamation occurs immediately after aggregate removal, although it may be impractical for enterprises that must combine mined material from various portions of the pit or quarry. Segmental reclamation is cost-effective, establishes final slopes as part of the mining operation, and works best in homogeneous deposits since it follows the removal of minerals in defined areas of the mine. Interim reclamation uses fast-growing grasses or legumes to temporarily stabilize disturbed areas before implementing the ultimate reclamation plan. After the mine has been depleted, postmining reclamation does not begin, which may result in the deterioration of stockpiled soils, a prolonged revegetation time frame, and a greater bonding liability (3).

As an example of the underground mine, there are over 600 known abandoned mines, the majority of which are abandoned underground chambers and pillar mines In North Dakota (4). Deep collapse features, often known as sinkholes, have emerged in various regions as these abandoned underground mines have degraded over time. These characteristics are particularly hazardous when they exist in or near residential and commercial areas, as well as public routes. To eliminate underground mine dangers, the Abandoned Mine Lands Division has adopted two main planning. Filling sinkholes and other subsidence features that have already collapsed to the surface is the first step. The second strategy involves remotely filling underground mine cavities with slurry or cementitious grout to prevent sinking (4).

The main three benefits of mine reclamation are restoring land's surrounding ecosystem, providing aesthetic and commercial value, and improving air and water quality. All landscape reclamation has two main stages technical and biological rehabilitation (5). In addition, identification and preparation of topsoil are also very important for the rehabilitation area after technical reclamation.

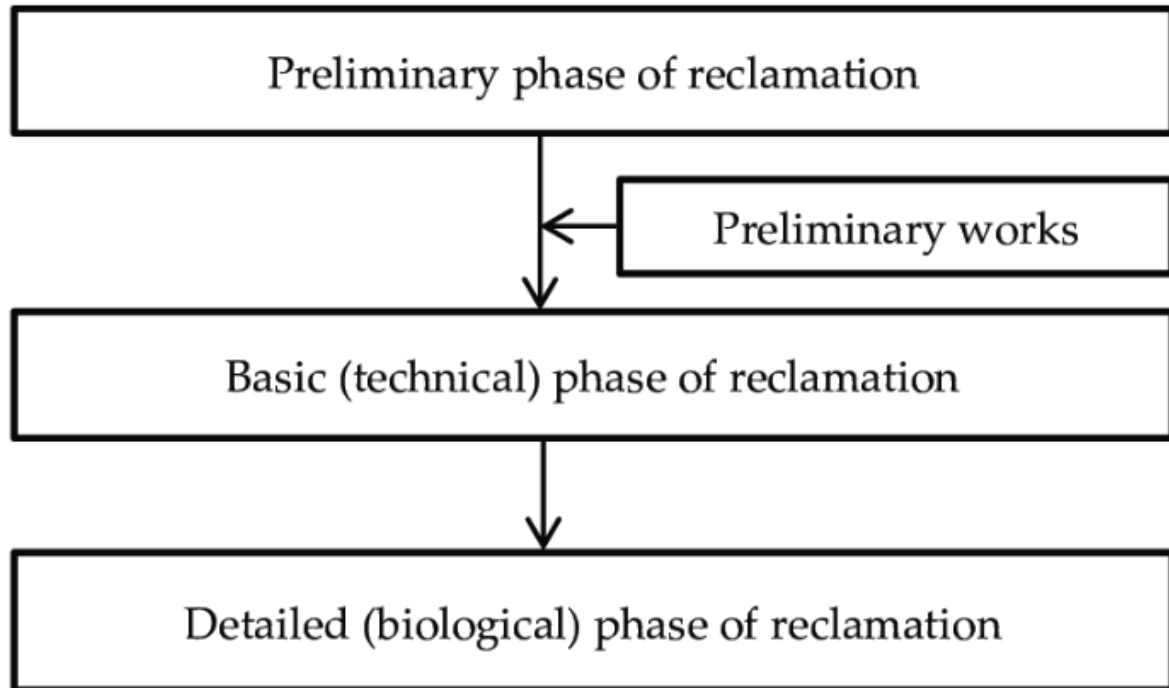


Figure 2. Three phases of mine reclamation

The laws and regulations that we should follow during mining rehabilitation in Mongolia:

- MNS 5915:2008 Environment, Classification of land destroyed due to mining activities (This standard applies to the development and implementation of rehabilitation projects and rehabilitation of land disturbed by mining operations)
- MNS 5916:2008 Environment, Requirement for fertile soil removing and its temporary storage during the earth excavation (The purpose of this standard is to define the requirements for stripping and storing fertile soil during earthworks)
- MNS 5918:2008 Environment, re-vegetation of destroyed land. General technical requirements (This standard specifies the requirements for planting vegetation in disturbed areas)
- MNS 5917:2008 Environment, reclamation of land destroyed due to mining activities. General technical requirements (the purpose of this standard is to specify the requirements for rehabilitation area)

2.2.2 Technical rehabilitation

Underground small-scale mining creates holes in the ground and stockpiles on the surface, and after mining activities, technical rehabilitation will be performed at the first. Technical rehabilitation will be performed in accordance with the standard MNS 5917:2008 “Environment,

reclamation of land destroyed due to mining activities. General technical requirements” for the lands damaged by mining activities in Mongolia. Technical reclamation consists of a wide variety of activities such as refilling, capping, recontouring, stripping, topsoil re-covering, and making drainage systems and haul roads. Some preparation work should be done well before the technical rehabilitation itself in order to be effective such as assessing land uses of the area in the future, undertaking hydrological assessment, and taking a note of the site-specific conditions of the surrounding context so on. The framework of the technical rehabilitation processes (6):

- Define boundaries of the area to be rehabilitated
- Planning based on the estimation of workload required in terms of labor, the timeframe for work to be completed, identification of financial sources required to undertake the rehabilitation work, and preparation of required tools and equipment.
- Waste management
- Estimation of the infill materials
- Conducting technical rehabilitation

Estimation of the backfill materials is calculated by the below formula(7):

$$V = (S_1 * h_1) + (S_2 * h_2) + \dots + (S_n * h_n)$$

V – total volume of the pits at the site, m³

S₁, S₂, ... S_n – average diameter of stockpile (area) at the site, m²

h₁, h₂, ... h_n – average depth of stockpile at the site, m.

2.2.3 Biological rehabilitation

Biological rehabilitation is the final stage of mining reclamation. Before the biological reclamation phase, identification and preparation of topsoil are important in the abandoned mining site. Calculation of the appropriate amount of the topsoil should be estimated based on the area disturbed and topsoil depth, where the indicative topsoil layer should be not less than 10 cm thick. The formula to be used for calculating the total amount of topsoil (7):

$$V = S * h$$

V – topsoil volume, m³

S – area to be covered by soil, m²

h – topsoil depth, m.

After technical rehabilitation, the surface of the area that has not been covered with topsoil for a long time shall be covered with fertile soil after scratching at least 18 cm deep. Biological rehabilitation will be performed in accordance with the standard MNS 5919:2008 “Environment, Re-vegetation of destroyed land. General technical requirements” for the areas damaged by mining activities in Mongolia. The framework of the technical rehabilitation processes:

- Vegetation of the area, and the capacity of the surrounding environment to assist the natural recovery of such vegetation
- Identification of relevant vegetation communities and preparation of species lists
- Tree and shrub planting
- Grass or herb planting

When planting degraded land, the type, species, and planting method of plants shall be selected taking into account the soil components, mechanical composition, land slope, and other conditions of the area. If the mechanical composition, fertility, and pH value of soil that is used for the topsoil do not meet the requirements of the relevant standards, measures shall be taken to fertilize with nutrients and mineral fertilizers and to improve the mechanical components.

2.3 Coal combustion by-products

Coal is a nonrenewable fossil fuel and is the main source of energy at present as well in Mongolia. Coal combustion by-products (CCBs) are generated during the process of burning coal by power plants and by coal combustion in the ger district. Mongolian power plants generate more than 800.000 t/a of CCBs (1). Most of the CCBs are usually thrown away without any environmental and economic benefits. Not all coal combustion products are wasted. The impact of coal usage on economics and surrounding can be reduced by using the coal combustion by-products for mining backfilling material in the rehabilitation process and construction materials. The four general types of ash produced are: fly ash, bottom ash, and boiler slag. Currently, the most widely accepted disposal practices for fly ash are: landfilling, stockpiling, and storage in settling ponds. Only about 25% of the solid residues from coal combustion, i.e., fly ash and bottom ash are utilized. The main uses include partial substitution

in cement mixes, road fills, and bases, and asphalt mixes. Fly ash is a heterogeneous mixture of amorphous and crystalline phases and is generally considered to be a Ferro aluminosilicate mineral with Al, Ca, Fe, K, Na, and Si as the predominant elements (8). The pH value of fly ash of coal can be between 4.5 and 12.0 depending on the sulfur content of the parent coal.

The mineralogical, physical, and chemical properties of coal fly ash depend on the nature and properties of the parent coal and the conditions under which they were produced, and they have been extensively reviewed. Coal fly ash is comprised of very fine particles, with an average diameter <10 μm , aggregated into spherical particles of 0.01-100 μm sizes which are hollow spheres (cenospheres) filled with smaller amorphous particles or crystals (pelospheres) (9). The chemical characteristics of coal fly ash depend largely on geological factors related to the coal deposits and on different operating conditions/practices employed at the power plants. Thus, fly ash from every coal-fired plant has its chemical characteristics. The main constituents of fly ash of coal are silica, alumina, and iron oxides, with varying amounts of carbon, calcium, magnesium, and Sulphur (9).

2.4 Backfilling

Backfill is a filling process of excavated holes for providing support and storage for wastes (fly ash, rocks, etc.) by using appropriate filling material. It is one of the important activities after mine closure to prevent some accidents relating to the landslide and rehabilitate the area. The mine backfill process is directly dependent on the type of mine, the tailings, backfilling materials, and the location of the stope or void. Advantages of backfilling (10):

- Helping to support the mine structurally, making it safer.
- Improving ventilation in the mine.
- It can reduce acid rock drainage, which contaminates water sources.
- It prevents roof falls when blasting underground.
- Reducing the need for surface storage space.
- It lessens the environmental impact of mining when the mine is closed.
- When used in room and pillar mining, it prevents the mine from collapsing after extracting minerals from the pillars.
- It makes it possible to extract minerals left in pillars in room and pillar mining.
- It reduces the risk of spontaneous rock bursts.
- It minimizes groundwater contamination when used with binders.

2.5 Review of backfilling method

Around the turn of the century (the 1900s), mine tailings and other types of waste materials are introduced into underground mines mostly for waste disposal purposes without full knowledge of backfill properties and other consequences. The backfilling process consists of returning material removed during extraction to the underground part of the mine.

Backfills can be divided into two main categories, cemented or uncemented. Cemented backfills generally include a small dosage of pozzolanic binder such as cement, fly ash, etc. to improve the strength. Cemented backfills incorporate the use of a small amount of binder material, normally Portland cement, or a blend of Portland cement with other pozzolans such as fly-ash, gypsum, or blast furnace slag to the parent backfill material to produce a binding agent for the fill. Cement Hydraulic Fill is the most common type of cemented backfill (11). Generally, hydraulic backfill, paste backfill, and rock backfill methods are used in common in the world. Backfilling of these types and their properties are shown in Table 1 (12).

Table 1. Classification of backfill and their properties (12)

Properties	Rock Backfill	Hydraulic Backfill	Paste Backfill
Waste ratio	100 %	60-75 %	75-85%
Binder	Cemented or not-cemented	Cemented or not-cemented	Only cemented
Water/Cement ratio	Low W/C ratio High binder strength	High W/C ratio Low binder strength	Low W/C ratio High binder strength
Barricade	Not required	Expensive	Cheap
Transport	Transportation shaft Mobile equipment	Drillhole and pipeline	Drillhole and pipeline
Grain size	> 20cm	>20 μm (>90%)	>20 μm (>15%)
Placing speed	100-400 ton/hr.	100-200 ton/hr.	50-200 ton/hr.
Investment cost	High	Low	High
Operational cost	High	Medium	Low
Advantages	High strength Easy material supply No water problem	Easy material supply Graded waste used Widely used	Low cement usage All waste usage Easy application
Disadvantages	High transport cost Structure of cavities Plant waste not used	Drainage of excessive water High cement usage / low strength	High-tech required (pumping and dewatering process)

Hydraulic backfilling

The use of hydraulic backfill systems became common in the 1940s and 1950s. The typical system consists of a slurry mixer, pump, and pipe for distribution. The addition of Portland cement to portions of backfill materials such as scraping floors in cut and fill holes was initiated in the late 1950s. The hydraulic backfill is defined as the filling of cavities resulting from mining operations by transferring the appropriate size of the material with water to the ground by pipeline extending from the surface, the separation of excess water from solid backfill material, and the hardening cycle (12).



Figure 3. Process of hydraulic backfilling (13)

Paste backfilling

Paste backfill is similar to surface paste deposition. The tailings are dewatered to generally >65% solids (by weight) and pumped underground, generally by positive displacement pumps. The paste has a homogenous appearance and produces a measurable slump (visible when released from a cone-shaped slip mold (Abrams)). When the paste is deposited underground there is little to no bleeding of the contained water.

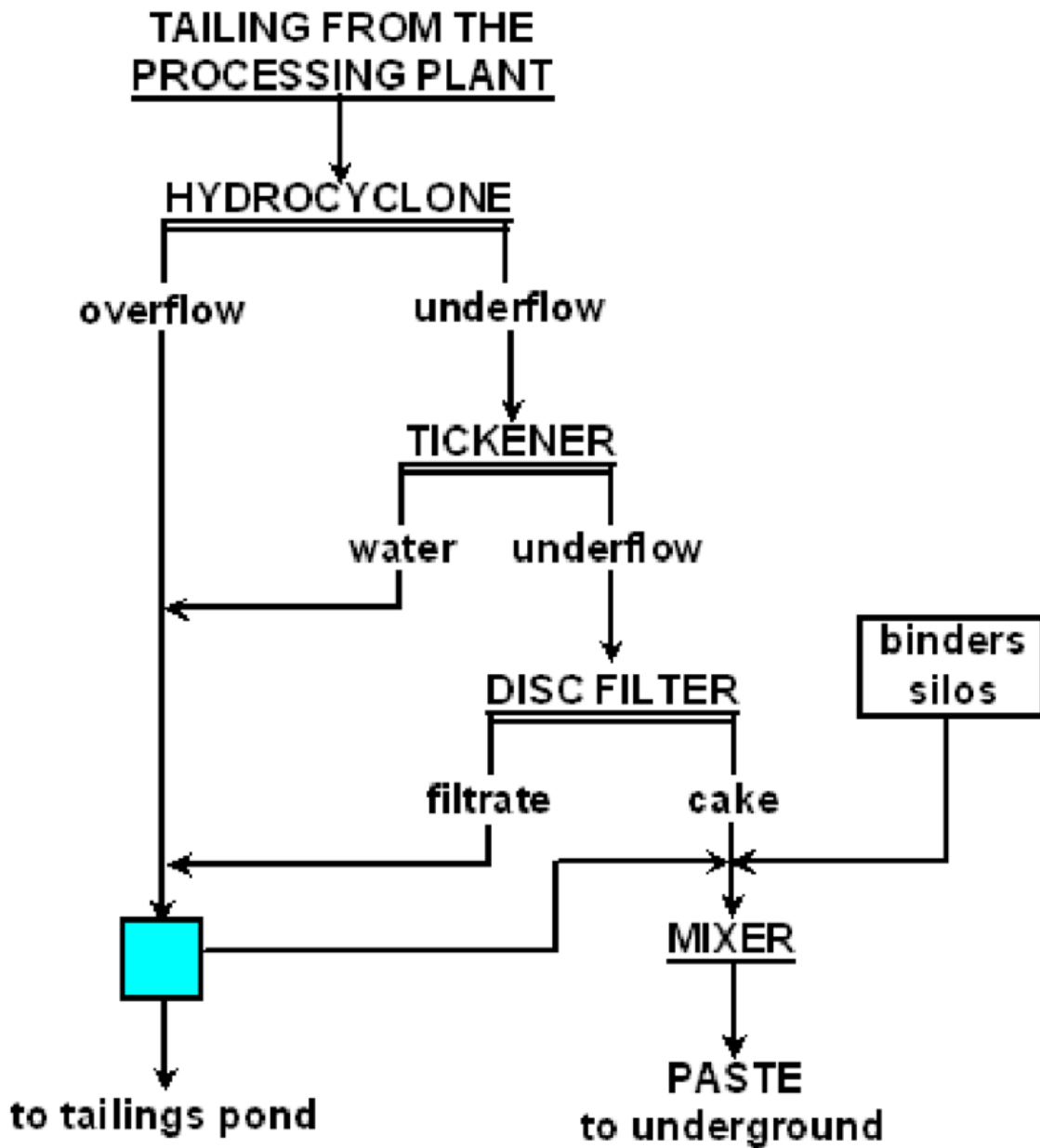


Figure 4. Flow sheet of paste backfill (14)

Rockfill

Rockfill and cemented rock fill were introduced in the 1960s. Rock fill is rock waste, surface sands, gravels, or dried tailings. The fill is either dropped down a raise or tipped into an open stope by a Load Haul Dump (LHD) or dump trucks. Dry rock fill is most suited for the cut and fills mining method.

2.6 Mongolian example of the backfilling method

MDU LLC has implemented a project named “Rehabilitation of 1-hectare mining area” in 2020 and its location is Nalaikh coal mining area, Nalaikh district, Ulaanbaatar.



Figure 5. 1-hectare rehabilitated area (15)

Table 2. Coordinates of rehabilitated area

No	X	Y
M-1	47° 44' 46.26"N	107° 16' 09.17"E
M-2	47° 44' 46.24"N	107° 16' 9.17"E
M-4	47° 44' 48.53"N	107° 16' 06.69"E
M-5	47° 44' 50.81"N	107° 16' 10.04"E

As for waste management, large rocks, waste, and disposal were removed from the area to prepare for making rehabilitation. 1 truck or 18 m³ of construction waste, household waste, animal carcasses, piles of bones, large stones, and foundation blocks were disposed of at the local landfill.

Technical reclamation was performed according to the MNS 5917:2008 standard “Rehabilitation which was destroyed by mining activities”. The company used fly ash from the Amgalan Power Plant to refill all pits, shafts, stockpiles, and trenches. There were 3 shafts within the 1-hectare area (15).

Table 3. Coordinates of mining shafts were backfilled with fly ash from the Amgalan Power Plant.

№	X	Y
M-1	47° 44' 49.15"N	107° 16' 10.30"E
M-2	47° 44' 48.35"N	107° 16' 07.42"E
M-4	47° 44' 47.25"N	107° 16' 08.53"E



Figure 6. Fly ash of Amgalan power plant (15)

To the current knowledge, this kind of backfilling technology is the first-ever known method in the Nalaikh area, probably in Mongolia. But, the project contains some disadvantages. These are:

- lack of research work about detailed information on fly ash, its compositions, characteristics, and so on.
- environmental status before the rehabilitation process.

According to this thesis work, soil samples were taken from the study area and tested in the GMIT processing laboratory to analyze heavy metals, soil texture, and mechanical compositions. Additionally, a soil profile was made in this rehabilitated area.

2.7 The BASMIC project

The main objective of the BASMIC project was to investigate whether there are opportunities to use at the German-Mongolian Institute for Resources and Technology (GMIT), Ulaanbaatar, Mongolia, CCBs from the power plants for backfilling and securing abandoned

small mining sites in Nalaikh, which is one of the nine districts of Ulaanbaatar city(1). Regarding the project, nine types of CCBs are tested in a laboratory.

Table 4. Sources of coal combustion by-products (16)

Number	CCB source
1	Baganuur Cyclone Ash
2	Baganuur Bottom Ash
3	Nalaikh Military Ash
4	Nalaikh Cyclone Ash
5	Nalaikh Bottom Ash
6	Nalaikh Ger District Ash
7	Thermal Plant Bottom
8	Thermal Plant Fly Ash
9	Glear Project Dust

Eight kinds of experiments have been conducted to analyze the chosen CCBs(1):

1. A sieve analysis (GMIT Processing Laboratory)
2. Moisture test (MNS ISO 589:2003 at GMIT Processing Laboratory)
3. XRF- Chemical analysis (AXIOSmAX at Geological Central Laboratory of Mongolia)
4. Radiation measurement (GMIT Processing Laboratory)
5. Elution test (LLC-ISO-MNS 11885:2007 at Khanlab Laboratory)
6. Unconfined compression test (GMIT Processing Laboratory)
7. FT-IR measurement (MFST Institute of Physics and Technology)
8. SEM analysis (ISO 13322-1:2014 at MFST-Institute of Physics and Technology)

After sieving and grinding processes, CCBs have been classified into binder and filler materials by using the content of pozzolanic reactants in CCBs. During the laboratory test, the different mixtures have been used to shape, water, and subsequently dry cubic blocks (16) The blocks that have been modified with cement represent all properties to be applicable for backfilling purposes. Most of the designs that used Portland cement as a binder satisfied the

requirements. The main reason is to using Portland cement is for increasing strength into the safe range.

As a result of the investigation, CCBs can be recovered to be backfilling material except for the GLEAR Project ash due to an incomplete combusted coal dust. The most appropriate one is fly ash of Thermal Power Plant #4 to use as a backfilling material in small-scale coal mining in the Nalaikh district.

3. Methodology and materials

3.1 Soil sampling

The soil sampling process was done according to the standard MNS 3298:1990 Environmental protection, Soil, General requirements on the probe for analytical purposes. 14 soil samples (Table 4) were taken from 8 points including 2 soil profiles. Those spots included the rehabilitated area which was used fly ash for the backfilling material in small-scale coal mines, an abandoned mining site, a nearby Nalaikh landfill area, and a reference soil area.



Figure 7. Soil samples of the rehabilitated area



Figure 8. Soil samples around Nalaikh's mining area

Table 5. Coordinates of the soil samples

No	Code	Depth	X coordinate	Y coordinate	Elevation	Explanation
1	A01	0-10 cm	47°44'48.58"N	107°16'11.62"E	1486 m	Rehabilitated area
2	A02	0-10 cm	47°44'43.77"N	107°16'13.65"E	1491 m	Mining area
3	A03	0-10 cm	47°44'45.14"N	107°16'33.68"E	1474 m	Mining area
4	A04	0-10 cm	47°44'47.71"N	107°16'34.31"E	1470 m	Mining area
5	A05	0-10 cm	47°45'4.92"N	107°16'33.58"E	1460 m	Mining area
6	A06	0-10 cm	47°45'7.56"N	107°16'34.96"E	1454 m	Landfill area
7	A07	0-10 cm	47°45'52.96"N	107°13'25.44"E	1546 m	Reference, topsoil
8	A08	10-35 cm	47°45'52.96"N	107°13'25.44"E	1546 m	layer 2
9	A09	35-55 cm	47°45'52.96"N	107°13'25.44"E	1546 m	layer 3
10	A10	55-70 cm	47°45'52.96"N	107°13'25.44"E	1546 m	layer 4
11	A11	0-10 cm	47°44'49.15"N	107°16'10.30"E	1489 m	Rehabilitated area, topsoil
12	A12	10-25cm	47°44'49.15"N	107°16'10.30"E	1489 m	layer 2
13	A13	25-60 cm	47°44'49.15"N	107°16'10.30"E	1489 m	layer 3
14	A14	60-70 cm	47°44'49.15"N	107°16'10.30"E	1489 m	layer 4

3.2 Mechanical composition

The mechanical composition of the soil describes the content in the soil of the elementary particles of different sizes. In other words, it is the texture of the soil which is the

proportion of the sand, silt, and clay. Because it affects nutrient absorption, soil texture is crucial in nutrient management. Finer grained soils, for example, have a greater potential to hold soil nutrients. Riffle splitter, balance, and series of sieves in a sieve shaker used in the laboratory for the analysis of the soil sample. The measurement of grain size is an attempt to determine the relative composition of the different grain sizes (sand, silt, clay) that constitute the soil mass. Many of the physical and chemical properties of the soil depend on how fine (clayey) or coarse (sandy) a soil is. The mass of soil held on each sieve has to be measured after the completion of the shaking period. 2 mm, 50 μm , and 25 μm sieves were used for determining soil texture.



Figure 9. Sieve shaker

Many of the physical and chemical properties of the soil depend on how fine (clayey) or coarse (sandy) a soil is. The mass of soil held on each sieve has to be measured after the completion of the shaking period.



Figure 10. Mechanical composition of soil after sieving

Using the soil texture triangle, the mechanical composition can be determined. The sides of the soil texture triangle are scaled for the percentages of sand, silt, and clay.

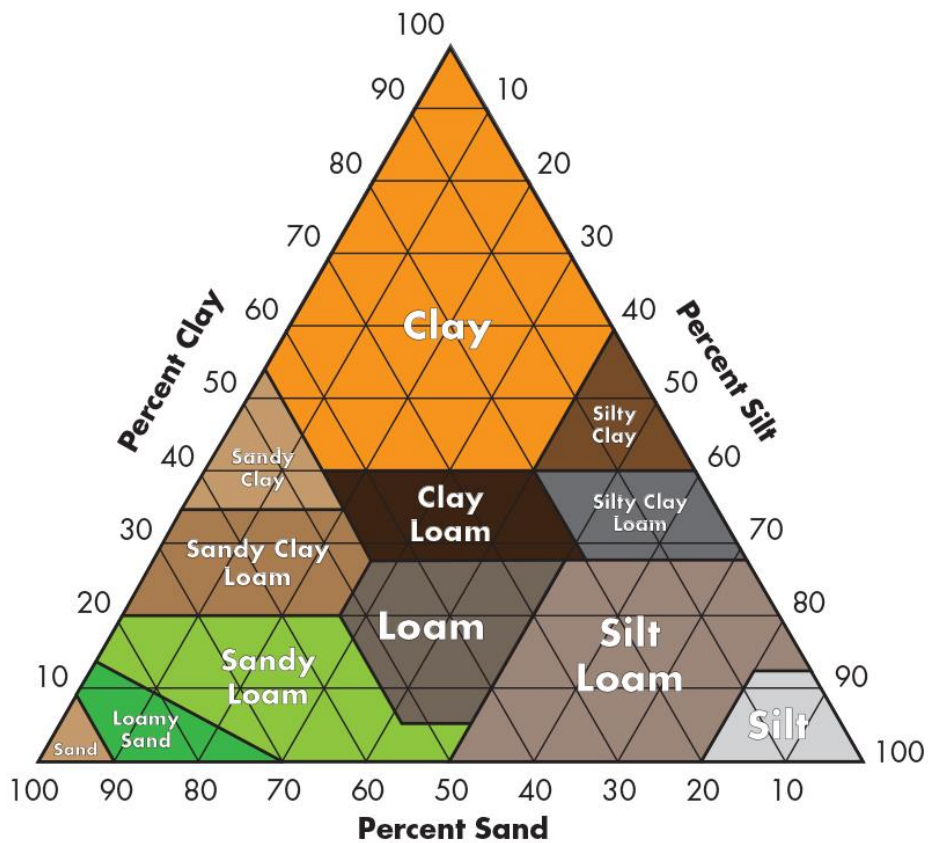


Figure 11. Soil texture triangle(17)

Table 6. Amount of mechanical composition of the soil samples

	Initial mass, W ₀ [g]	Soil weight in the sieve			
		W ₁ , [g] (2mm-50µm)	W ₂ , [g] (50-25µm)	W ₃ , [g] (<25µm)	total soil mass W, [g]
A01	52.32	50.2	1.47	0.1	51.77
A02	52.53	48.35	1.79	0.41	50.55
A03	52.23	50.52	1.11	0.03	51.66
A04	52.38	49.84	1.43	0.13	51.40
A05	52.50	51.7	0.55	0.04	52.29
A06	52.36	50.34	1.64	0.11	52.09
A07	52.28	50.34	1.55	0.1	51.99
A08	52.25	49.53	2.18	0.15	51.86
A09	52.61	48.04	3.42	0.37	51.83
A10	52.36	48.34	3.1	0.38	51.82
A11	52.52	47.89	7.09	0.42	55.40
A12	52.88	48.21	3.74	0.42	52.37
A13	52.81	51.98	0.55	0.03	52.56
A14	52.26	44.62	3.33	0.41	48.36

3.3 Heavy metals

Heavy metals, a key factor of soil pollution, do not decompose and are stored in the soil for a long time. Those are a group of metals that are Pb, As, Hg, Cd, Zn, Ag, Cu, Fe, Cr, Ni, Pd, and Pt. By its negative impact on the environment and living organism, heavy metals are generally classified into toxic heavy metals (Pb, Cd, As, and Cr), toxic bio-active heavy metals (Cu, Zn, Ni, V, Sr, Mo, Co, Se), alkali metals (Ca, K, Mg, Na), and metals (Al, Fe, Ba, Mn). Heavy metals have the potential to alter soil properties, particularly biological properties (18). It can affect the biogeochemical cycle and heavy metals accumulate in the living organisms. They can withstand a long time because it is not eliminated by physical activity. Heavy metals' deleterious impact on soil microorganism proliferation and activity may have an indirect impact on plant growth. For example, a drop in the number of helpful soil microbes due to excessive metal concentrations may result in a reduction in organic matter breakdown, resulting in nutrient losses in the soil. Heavy metal interference with the activities of soil microorganisms may also impede enzyme activity important for plant metabolism. These

harmful effects (both direct and indirect) cause a decrease in plant development, which might lead to plant mortality.

The non-destructive analytical technique XRF (X-ray fluorescence) is used to determine the heavy metals in the soil. By detecting the fluorescence (or secondary) X-ray released by a sample when it is excited by a main X-ray source, XRF analyzers may determine the chemistry of a sample (19). XRF, unlike many laboratories' equipment, does not require any acid digestion techniques prior to analysis, making it a helpful screening tool.



Figure 12. XRF analyzer

Table 7. Heavy metals in the soil samples

No	Unit	Cu	Zn	As	Sr	Pb
A01	mg/kg	80	610	40	280	20
A02	mg/kg	110	250	20	270	20
A03	mg/kg	120	250	30	320	20
A04	mg/kg	120	250	20	270	20
A05	mg/kg	160	340	20	310	120
A06	mg/kg	430	350	20	280	30
A07	mg/kg	120	150	20	300	10

A08	mg/kg	110	270	20	310	20
A09	mg/kg	130	130	20	370	10
A10	mg/kg	70	250	20	350	10
A11	mg/kg	220	195	10	325	20
A12	mg/kg	390	270	15	335	15
A13	mg/kg	210	235	10	360	15
A14	mg/kg	420	455	10	295	20
Maximum permissible level	mg/kg	100	300	20	800	100

3.4 pH value

This parameter determines the acidity and alkalinity of the soil. From the pH of the soil, the chemical processes that take place in the soil are direct and are inversely related. Soil environment 6.1-6.5 is considered to be weakly acidic. If the pH value of the soil is between 6.5 and 7.5, it is neutral. In general, when the pH value of the soil is between weakly acidic and weakly alkaline, 5.6-8.4, it is considered to be suitable for plant growth. The pH of the soil is directly related to the concentration of main nutrients and the composition of microelements accessible for plant absorption. Plants growing in exceptionally high or low pH soils may experience nutritional deficits or toxicities.

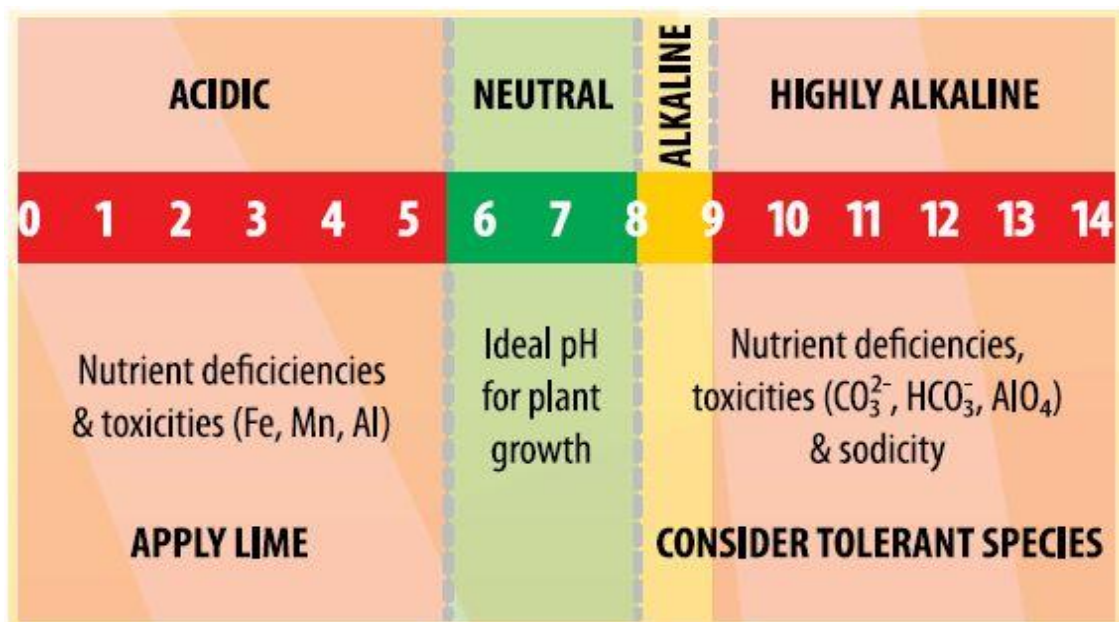


Figure 13. Classification of soils on the basis of pH, the implications for plant growth, and some management options(20)

Table 8. pH value of the soil samples

№	Code	pH
1	A01	6.75
2	A02	6.38
3	A03	7.71
4	A04	7.25
5	A05	7.34
6	A06	7.78
7	A07	7.01
8	A08	7.73
9	A09	8.71
10	A10	8.55
11	A11	7.32
12	A12	7.65
13	A13	8.65
14	A14	7.34

4. Study area

4.1 Introduction to study area

From 1954 to 1958, Nalaikh was built based on a large mining operation and became one of the districts in Ulaanbaatar. It is located around 36 km southeast of the capital of Mongolia. It covers a total area of 68.7 thousand square hectares with a population of 39323 (21). Nalaikh's coal mine was established in 1922 at first and produced over 600,000-ton coal within a year. Due to the explosion of methane gas, this coal mining has stopped in 1990. The Nalaikh basin has a hilly prairie land surface that is 1,410-1,500 meters above sea level (22).



Figure 14. Rehabilitated area

4.2 Ecology

The Nalaikh basin is located in the Khentii mountains, which were formed by the subduction and accretion of different minor terranes from the Proterozoic to the early Mesozoic as part of the Altai-Central Asian belt (23). In Nalaikh, the Devonian layer is between 2500 and 3000 meters deep, while the Carboniferous deposits in the northwest basin are between 1500 and 2500 meters deep (22). During the Mesozoic epoch, magmatic activity surged, and powerful granite plutons impacted the Ulaanbaatar landscape in the Triassic and Jurassic periods. Furthermore, a broad area of stress in which magmatism was accompanied by a result

of the coal lithological basin generated the intramontane basin filled with lower Cretaceous deposits (23). The upper and lower sections of the Cretaceous sedimentary infill are separated by 300 to 350 meters of mostly siltstone and shale with the initial layer of coal, whilst the upper portion has a 280- to 300-meter-thick layer with a strong coal content. The coal deposit comprises a total of 12 coal seams with a depth of up to 15 meters that run over 10 kilometers in an east-west (E-W) direction, covering a distance of roughly 3.5 kilometers, and is known as the Choir-Nairga basin (23). Coal is made up of 18 percent ash, 47.3 percent volatile material, and 0.75 percent sulfur, with a moisture content of 9.3 percent and calorific values of 6536 kcal/kg and 27347 KJ/kg, respectively (23, 24).

4.3 Land use

Land use in Nalaikh is diverse, with grazing land accounting for one-third of the land, and urban and semi-urban communities, including concrete apartments and ger areas, accounting for 17% of the land. Infrastructure, such as paved streets and asphalt roads, occupy a very small percentage of the overall area, about 2%. Coal mining activities are the major use of land in Nalaikh. The coal resource is located in Tov Province and is part of the Middle-East Megablock (24). The Nalaikh coal mine began operations in 1922 and ceased operations in the 1990s. The emission of methane gas grew by up to 15 m³ per ton of coal extracted as the mine's operation progressed deeper. Many individuals lost their jobs as a result of the mine shutdown, and illegal mining activities began as a result. Despite a government resolution to ban mining, "ninja" miners continue to engage in small-scale, artisanal mining activities. There are around 200 operating mine shafts in the mining region, with 26 of them being approved. Throughout the peak season, up to 2000 "ninja" (illegal) miners work in the Nalaikh license mining region, extracting over one million tonnes of hard coal, 70% of which is carried into UB and burned in Ger areas for heating during the winter. Although working conditions do not meet the requirement of occupational health and safety, the number of deadly mine accidents and health problems among miners is increasing year by year, with some even losing their lives (24).

4.4 Climate

Climatology is one of the most important soil-forming factors. In this study, the climate condition of the Nalaikh valley is considered the same as the city of UB. The duration of the sunshine in Nalaikh is around 2804 hours per year and the daily average sunshine duration is 7.7 hours (35). Based on the average amount of precipitation between 1986 and 2016 is 258.5 mm of which 90% is precipitated from April to September. January is the coldest month in

Nalaikh with an average temperature of -24.1°C , whereas the warmest month is July with an average temperature of 14.7°C . Our study area has a cold, arid, and semi-arid condition because the temperature line is below the precipitation bar and the annual precipitation is 256 mm with an average temperature of -0.7 degrees Celsius. During the months from November to March, the amount of average precipitation is lower than 10mm with very cold weather conditions. The maximum speed of the wind is around 3.5 m/s in spring with the dominant wind direction line from west to the northwest all year round (23, 24).

5. Results & Discussion

As a result of the identification of heavy metals, four elements that are copper, zinc, arsenic, and lead were identified more dominant in the soil.

Copper (Cu) is a mineral that is required for plant growth. If the amount of Cu increases too much, it will influence negatively plants and soil. The maximum permissible level of Cu is 100 mg/kg in Mongolia. 86% of total soil samples exceeded from precaution value. The mean value is 192 mg/kg which is almost two times higher than the Mongolian standard (Table 9). The area which contains the maximum value of Cu is A06, around the landfill area of the Nalaikh district. Industrial and household wastes might be the main reason to pollute the around spot A6. In addition, spots A11, A12, A13, and A14 are the samples of the rehabilitated area and the main cause might be the fly ash of Amgalan power plant. Those show the higher value comparing to the reference soil and the Mongolian standard. The Cu concentration of the reference soil sample is also a little bit higher than the maximum permissible level.

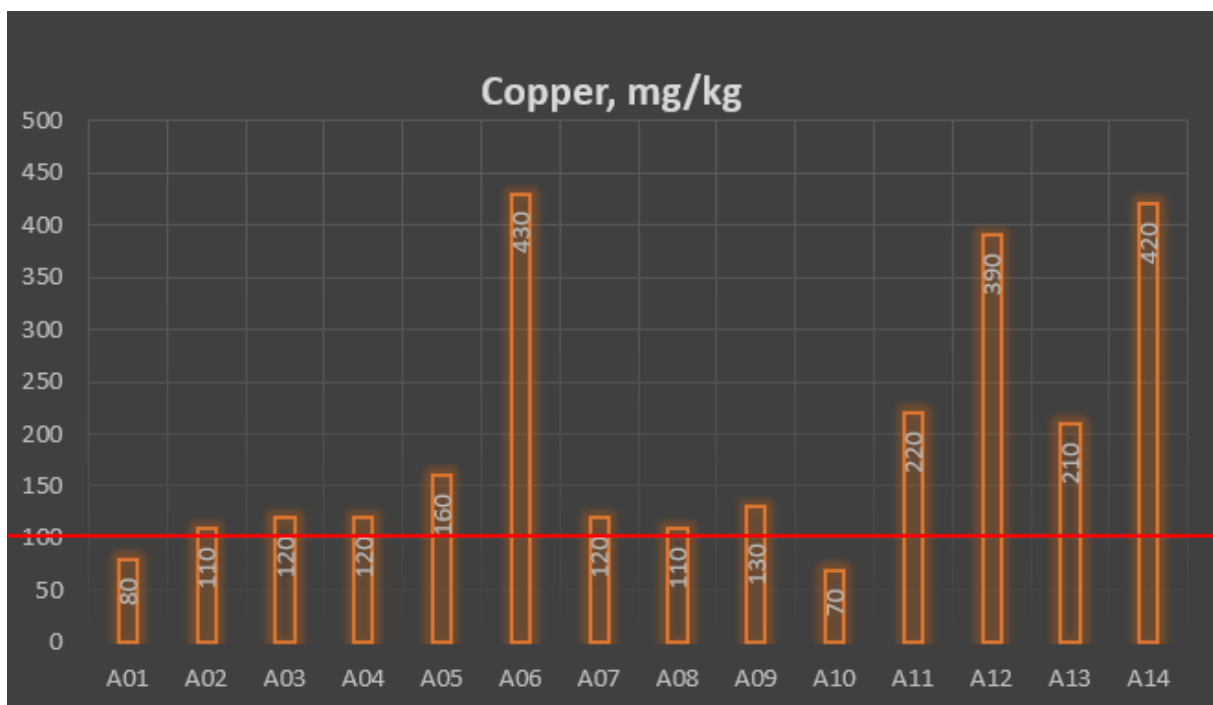


Figure 15. Copper pollution

The most significant sources of zinc in soil are discharges of smelter slags and wastes, mine tailings, coal and bottom fly ash, and the use of zinc-containing commercial products such as fertilizers and wood preservatives. The maximum permissible level of Zn is 300 mg/kg. The mean value is 286 mg/kg which did not exceed the precaution value (Table 9). 28% of the samples were contaminated by Zn and the most polluted area are rehabilitated area which was completed two years ago. Spots A1 and A14 are the soil samples from rehabilitated area. Backfilled fly ash might be influence to characteristics of the soil and its layer because it contains also high concentration of heavy metals. As concentration of spot A1 is 4 times higher than topsoil of reference soil sample and almost 2 times higher than Mongolian standard. A6 is nearby spot of landfill area of Nalaikh district which contaminates surrounding land all the time due to the mixed many types of wastes and its chemicals. Comparison with reference soil sample of layer 4, spot A14 is 1.7 times higher. It means rehabilitated area was polluted by Zn and its main reasons might be wastes and fly ash.

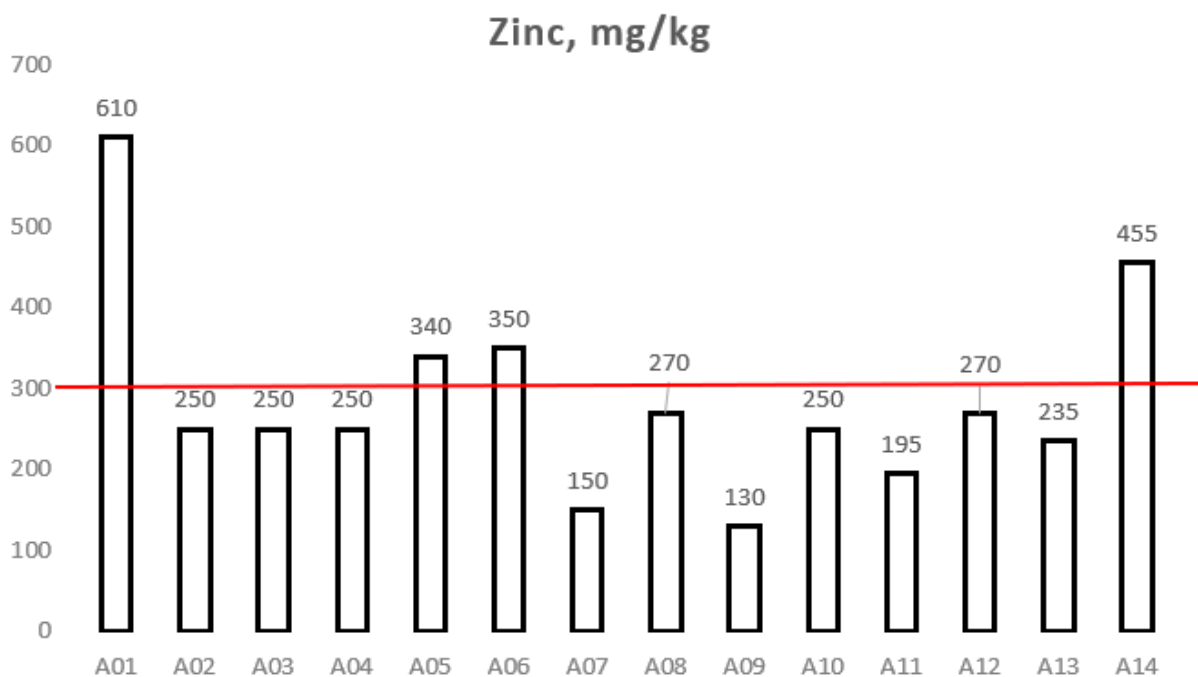


Figure 16. Zinc pollution

Arsenic in the soil is caused by human activities such as pesticide use, mining and ore processing, operating coal-burning power plants, and waste disposal. The mean concentration of As is 20 mg/kg which is exactly equal to the Mongolian standard. The maximum permissible level of As is 20 mg/kg in Mongolia. 50% of total soil samples are the same as the precaution value of the standard of As. Spot A01, rehabilitated area, was polluted two times higher than others. Heavy metals of backfilled fly ash is influenced to the topsoil, the reason why it is too high comparing with reference soil and the standard.

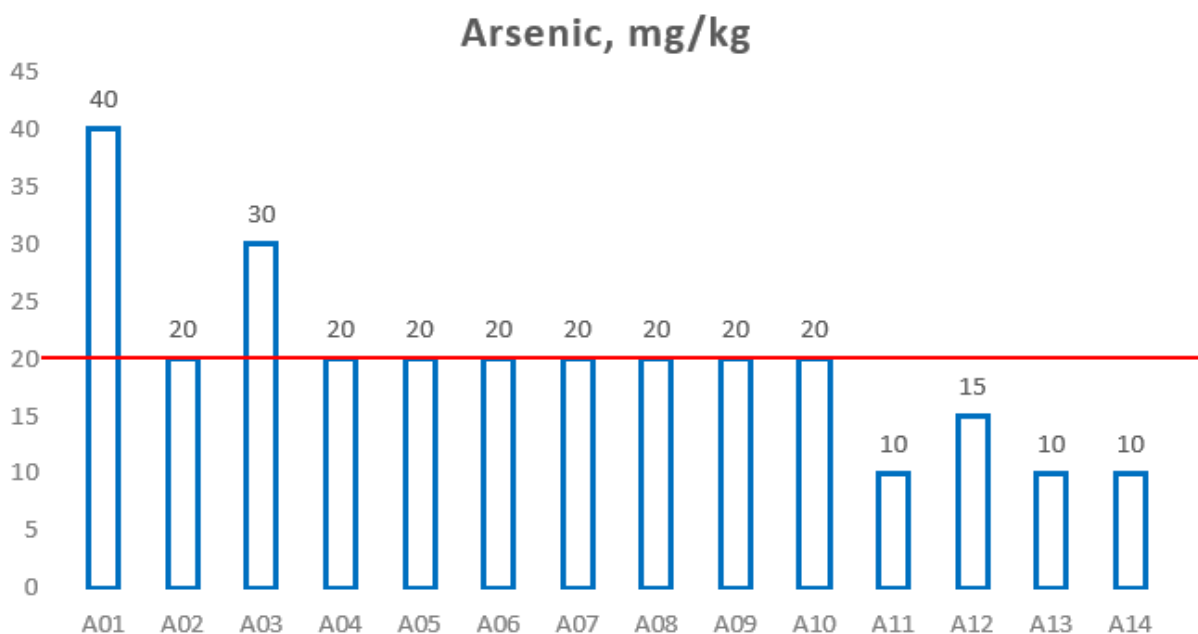


Figure 17. Arsenic pollution

Lead is the most common type of contaminant in the soil. The surface of very fine clay and organic matter particles holds soil lead securely. As a result, unless the soil has been disturbed by activities such as excavation for building or tillage for landscaping and gardening, lead tends to accumulate in the upper 1 to 2 inches of soil when put to the soil surface. The precaution value is 100 mg/kg in the soil. Only A05, the mining area, was contaminated by lead and exceeded the maximum permissible level. Compared to the reference topsoil, it is 12 times higher. Spot A05 is located just next to the mine hole, collapsed construction and the road. Those are the main reasons of pollution including residue of coal mine, construction materials, car emissions so on.

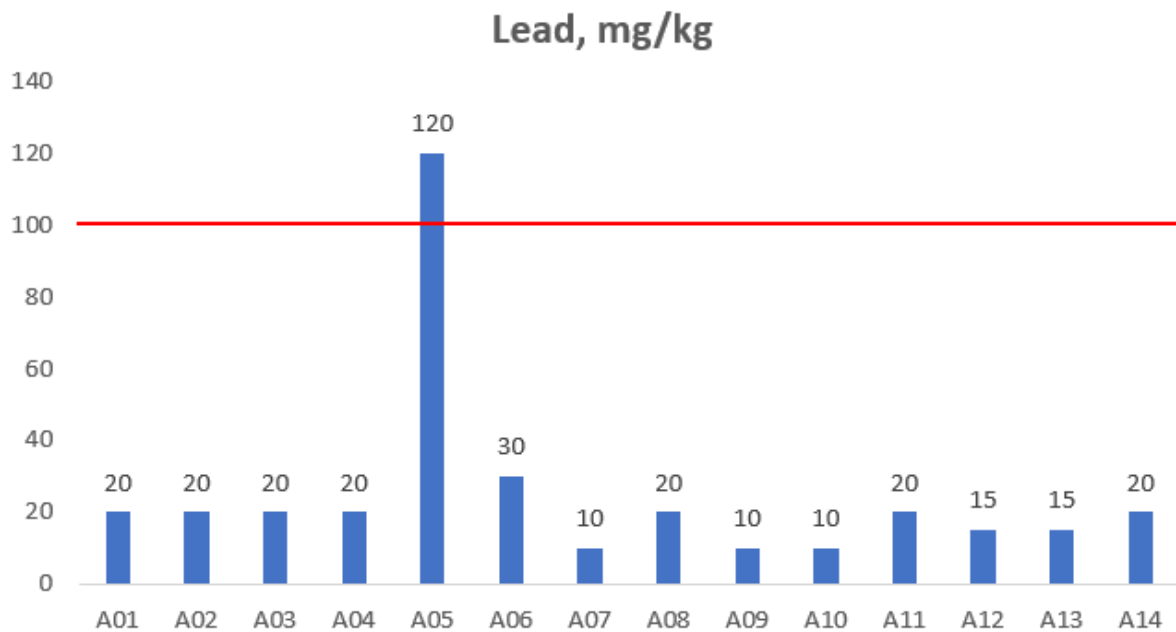


Figure 18. Lead pollution

Table 9. Some data of heavy metals

	Unit	Cu	Zn	As	Sr	Pb
Max	mg/kg	430	610	40	370	120
Min	mg/kg	70	130	10	270	10
Mean	mg/kg	192	286	20	313	25
MNS5850:2019	mg/kg	100	300	20	800	100

As for the pH value of the soil samples, 50% of it is alkaline, 49% of the spots are neutral, and left 1% is acidic. Reference soil is too alkaline compared to the other samples. Rehabilitated area's pH value is neutral except for backfilled fly ash of the Amgalan power plant. Most of the area has a suitable environment (pH) to grow a plant.

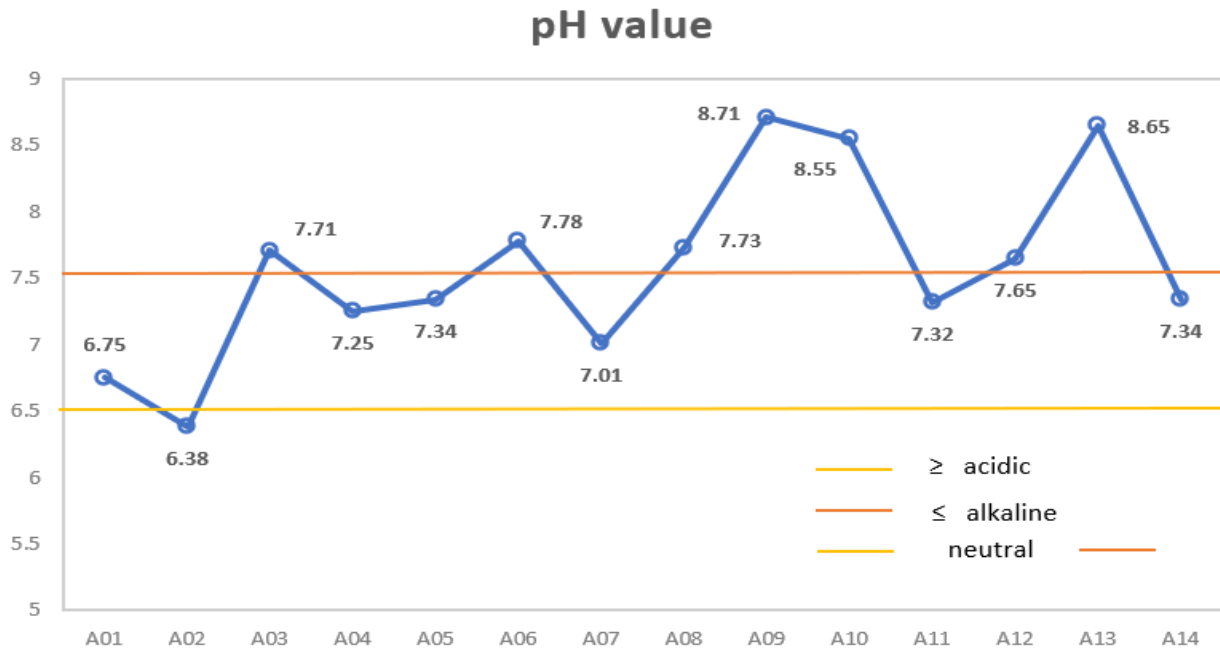


Figure 19. pH value of the soil samples

A perfect soil would have 45 percent minerals (sand, clay, silt), 5 percent organic (plant and animal) material, 25% air, and 25% water. Loam (20–30 percent clay, 30–50 percent silt, and 30–50 percent sand) would be the mineral component. But, the soil texture of 86 % of the soil samples is sandy except for the rehabilitated areas. The topsoil of the rehabilitated area is loamy sand. Even reference soil contains more sand, 96,26%.

Table 10. Soil texture by percent

№	Initial mass, W0 [g]	Soil weight in the sieve							Mass loss, [g]	Mass loss, [%]
		W1, [g] (2 mm-50 µm)	W1, [%]	W2, [g] (50-25 µm)	W2, [%]	W3, [g] (<25 µm)	W3, [%]	Total soil mass W, [g]		
		Sand		Silt		Clay				
A01	52.32	50.20	95.95	1.47	2.81	0.10	0.19	51.77	0.55	1.05
A02	52.53	48.35	92.04	1.79	3.41	0.41	0.78	50.55	1.98	3.77
A03	52.23	50.52	96.73	1.11	2.13	0.03	0.06	51.66	0.57	1.09
A04	52.38	49.84	95.15	1.43	2.73	0.13	0.25	51.40	0.98	1.87
A05	52.5	51.70	98.48	0.55	1.05	0.04	0.08	52.29	0.21	0.40

A06	52.36	50.34	96.14	1.64	3.13	0.11	0.21	52.09	0.27	0.52
A07	52.28	50.34	96.29	1.55	2.96	0.10	0.19	51.99	0.29	0.55
A08	52.25	49.53	94.79	2.18	4.17	0.15	0.29	51.86	0.39	0.75
A09	52.61	48.04	91.31	3.42	6.50	0.37	0.70	51.83	0.78	1.48
A10	52.36	48.34	92.32	3.10	5.92	0.38	0.73	51.82	0.54	1.03
A11	52.52	46.09	87.76	5.09	9.69	0.42	0.80	51.60	0.92	1.75
A12	52.88	48.21	91.17	3.74	7.07	0.42	0.79	52.37	0.51	0.96
A13	52.81	51.98	98.43	0.55	1.04	0.03	0.06	52.56	0.25	0.47
A14	52.26	44.62	85.38	3.33	6.37	0.41	0.78	48.36	3.90	7.46

Rehabilitated area of Nalaikh mining has a neutral pH environment and a loamy sand soil texture which is not suitable to grow plants. In addition, It was contaminated by copper and zinc.

6. Conclusion

In conclusion, this study conducted the investigation, field methods, and statistical analyses relating to the rehabilitated area and abandoned mining site. Metals and minerals are essential components of daily existence. People and communities all across the world rely on mining goods. Simultaneously, we all know that mining influences biodiversity and ecosystems. Reclamation methods must also restore environmental quality for mined landscapes to meet human requirements. Many mine sites have relatively undisturbed ecosystems that produce ecological benefits valued by human culture before mining. Reclamation strategies have also been developed that can be used to restore ecosystems, process, and function on postmining lands that resemble premining circumstances in some way.

By backfilling, efforts should be made to restore the original ground profile as far as possible. Before mining holes collapse to the surface, this approach can fill mine voids and rubblized areas and densify loose soil materials. Therefore, the backfilling method must be needed after finishing mining operations. In addition, investigation before backfilling and related academic research should be necessary to rehabilitate the area and analyze the monitoring activities.

As an investigation of the thesis work, the content of elements did not exceed maximum permissible values in most cases. The soils were contaminated by copper, arsenic, and zinc compared to the other heavy metals. The leading causes of the pollution are wastes (household, industrial, so on) and residues of coal (mining waste). Also, the soil texture did not meet the mechanical composition of the ideal soil. 86% of the soil samples have sandy soil texture, and others have loamy sandy.

We should consider more about soil and water contamination all the time, from the start to the closing of the mining operation.

7. Recommendation

The following issues should be taken into consideration:

- Urgently take measures to rehabilitate the abandoned small-scale coal mines in the Nalaikh area
- Identify abandoned small-scale coal mines for further backfilling plan
- Urgently carry out relevant research to identify the prior condition
- Develop guidelines, rules, and regulations to implement the backfilling method for an abandoned small-scale coal mines
- Provide technical recommendations on implementing the developed backfilling method
- Capacity building: carry out the training for workers to train backfilling method
- Conduct regular assessments after and before backfilling rehabilitation activities
- Implement the project which is backfilling rehabilitation of abandoned small-scale mines by using coal combustion by-products
- Plan other relevant activities

8. Statutory Declaration

Lkhagvajav, Baigali

15011383630359

Last Name, First Name

Student ID Number

I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

Experimental analysis on backfilling rehabilitation with Coal Combustion By-Products (CCBs) for abandoned Small Scale Coal Mines

I did not use any sources other than those stated. In case the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Ulaanbaatar, 2022.05.16

Place, Date

Signature

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10. Appendices

Table 11. Metals detected by XRF

Sample code	№	Unit	Ti	Mn	Fe	Cu	Zn	As	Rb	Sr	Zr	Ba	Pb
3773	A11	mg/kg	3365	710	24700	220	195	10	90	325	225	190	20
3775	A12	mg/kg	3525	675	25375	390	270	15	90	335	205	155	15
3777	A13	mg/kg	3615	1260	38700	210	235	10	120	360	180	200	15
3779	A14	mg/kg	3595	825	32335	420	455	10	100	295	220	210	20
3976	A01	mg/kg	2750	920	29880	80	610	40	80	280	200	240	20
3977	A02	mg/kg	2830	730	27100	110	250	20	80	270	190	290	20
3978	A03	mg/kg	3210	710	27280	120	250	30	70	320	180	270	20
3979	A04	mg/kg	2060	810	28400	120	250	20	80	270	220	400	20
3980	A05	mg/kg	1770	750	28590	160	340	20	90	310	150	320	120
3982	A06	mg/kg	1590	520	19250	430	350	20	90	280	190	350	30
3983	A07	mg/kg	1850	1080	28480	120	150	20	80	300	210	480	10
3984	A08	mg/kg	1220	1070	28060	110	270	20	80	310	250	570	20
3985	A09	mg/kg	-	960	25800	130	130	20	70	370	160	510	10
3986	A10	mg/kg	-	860	24570	70	250	20	70	350	200	430	10



Figure 20. Rehabilitated area of coal mine



Figure 21. Abandoned small-scale coal mine hole



Figure 22. Abandoned small-scale coal mine hole



Figure 23. Process of reference soil sampling